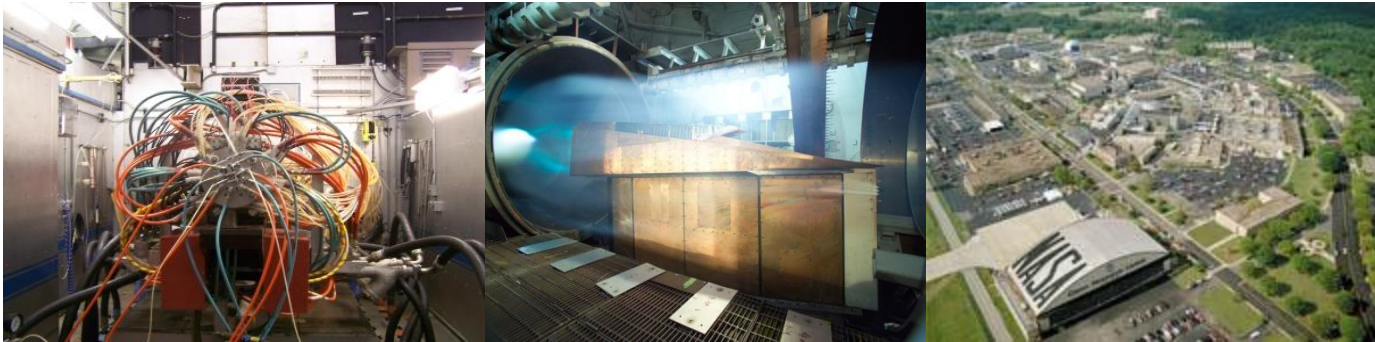


Life-Cycle Assessments of Selected NASA Ground-Based Test Facilities



Cutter Sydnor, Senior

Green Engineering Program, Virginia Tech

Agenda

- **Why LCA for NASA?**
- **Aeronautics Test Program (ATP)
Ground Test Facilities LCA**
- **Ames Research Center (ARC) Arc Jet
Complex LCA**
- **Test Facility LCAs: Lesson Learned**

LCA for NASA: Agency Benefits

- **LCA is an established, formal technique, capturing quantities in recognized units**
- **Infrastructure is expensive to upgrade and maintain; and mandated to be environmentally conscious**
- **Results and recommendations allow NASA to explore options and scenarios**

LCA for NASA: Facility Benefits

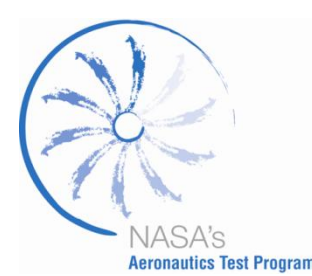
NASA Environmental Management

- **Executive Orders put focus on sustainability**
- **NASA completes annual GHG inventory**
- **Anticipation of future policies and restrictions**

Facility-Specific Opportunities

- **Baseline for future studies**
- **Tool to lobby for improvements**
- **Reduce inputs, reduce impact → reduce costs**

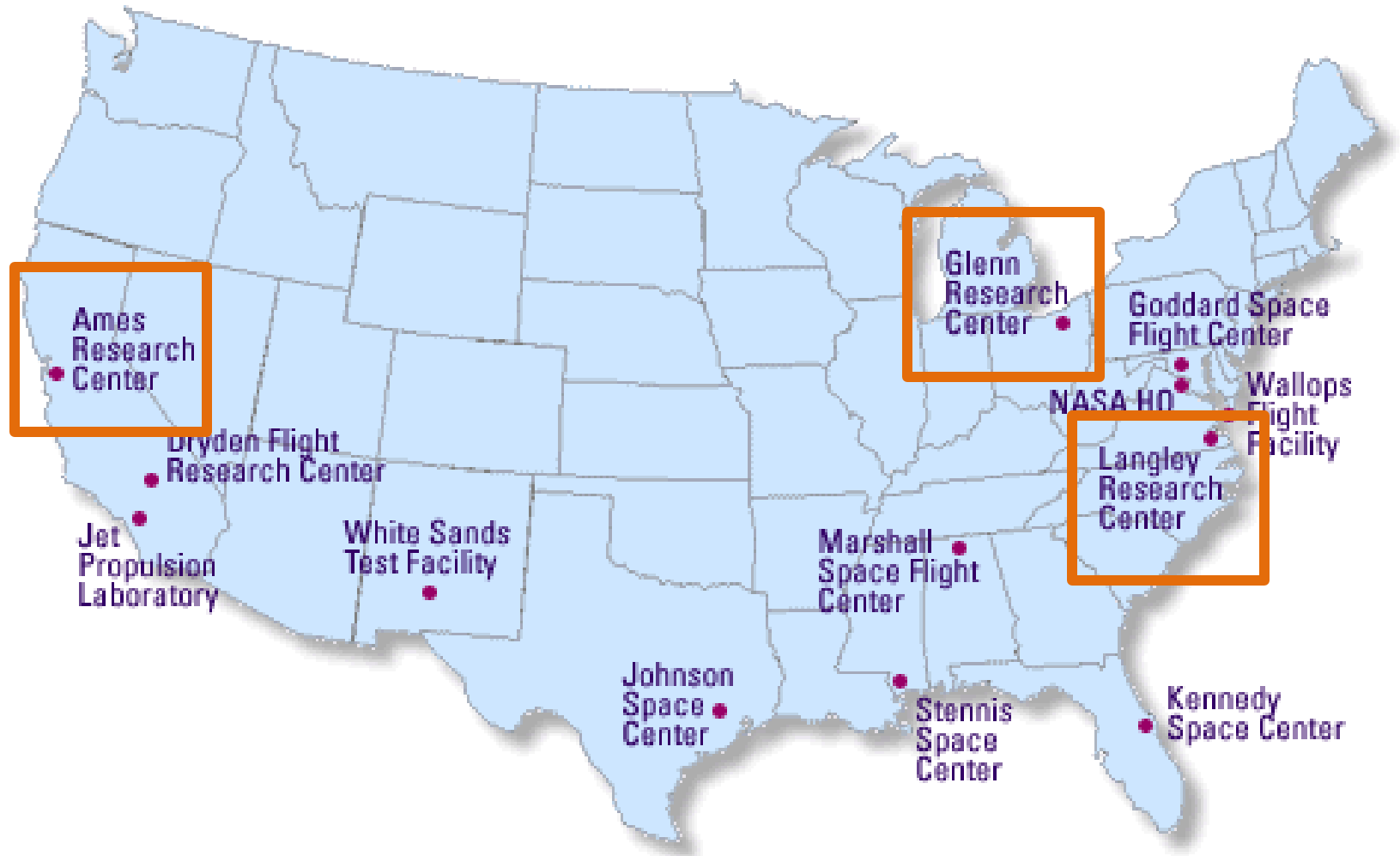
About ATP



NASA's Aeronautics Test Program (ATP) was established in 2006 to retain and invest in aeronautics test capabilities that are strategically important to the Agency and the Nation.

Efficiency and environmental impacts are a major focus of facility management.

ATP Centers and Ground Test Facilities – National View



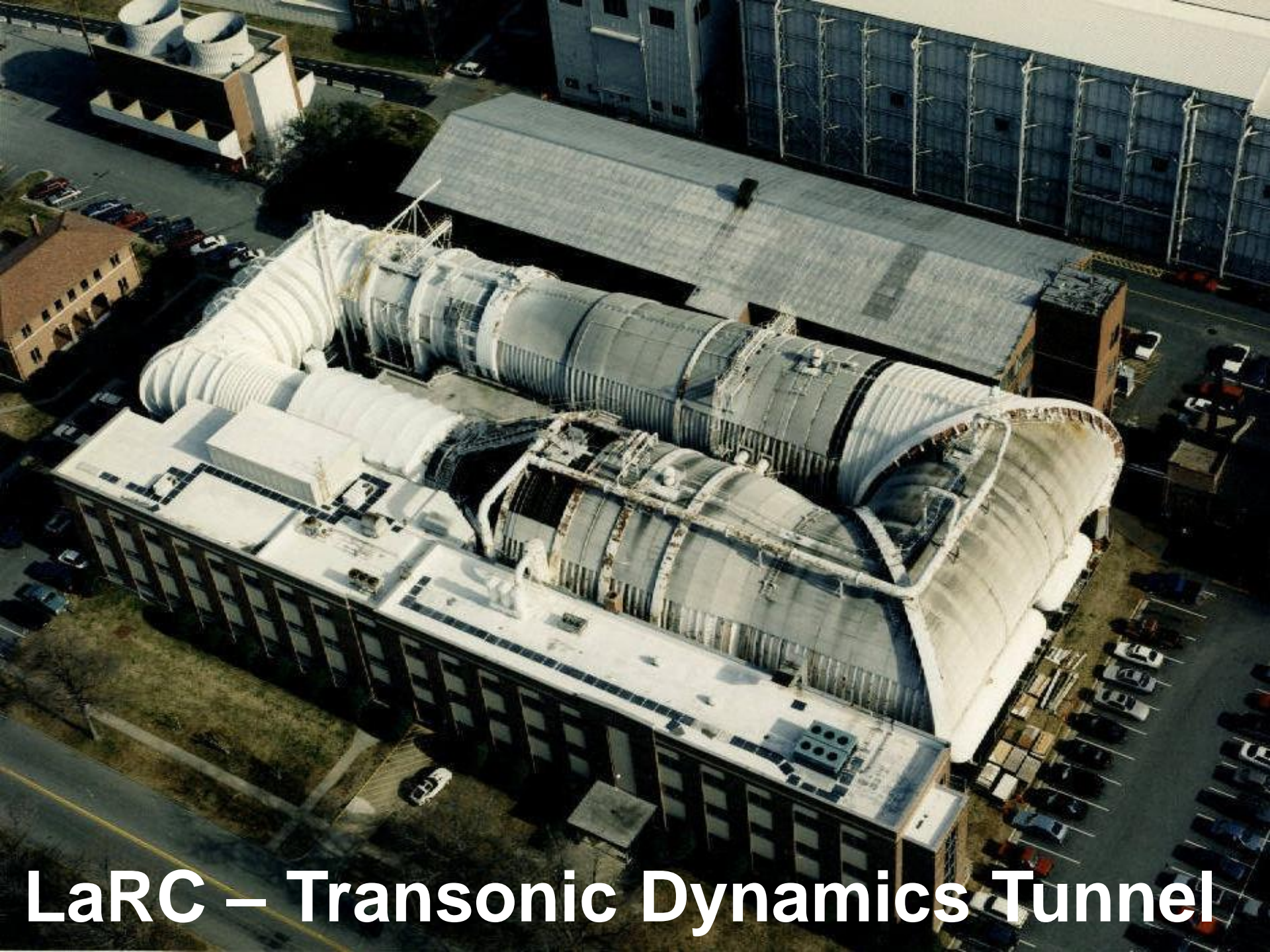
ATP Facility Project Overview

Goal: Determine the life-cycle carbon footprint and environmental impact of the operation phase of ATP's ground test portfolio over a typical fiscal year.

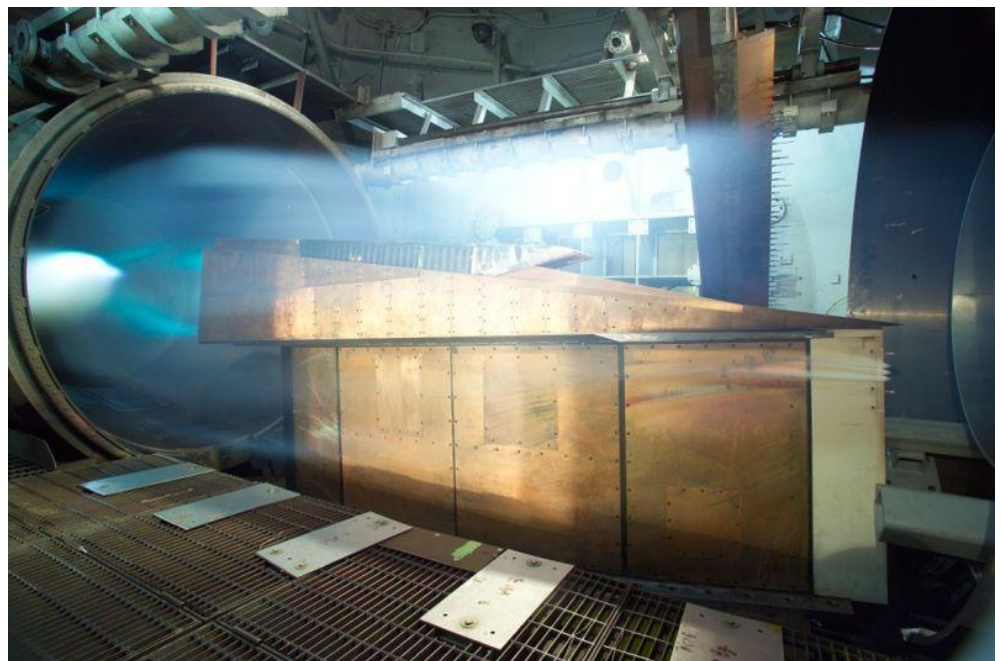
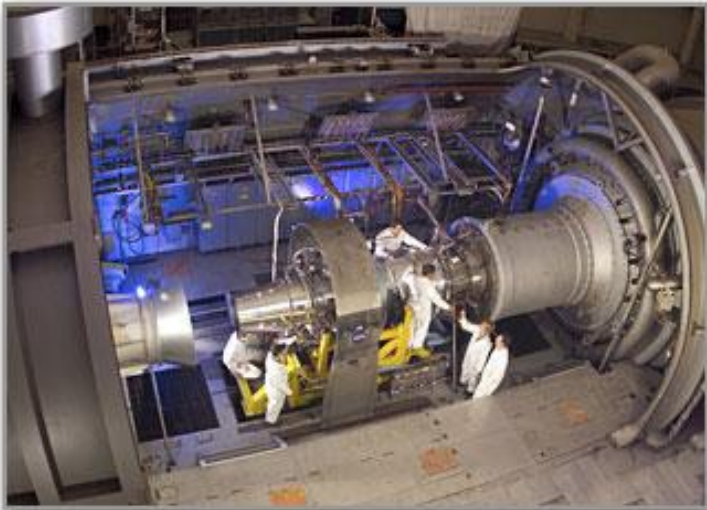
Result: Facility impacts depend on several factors but overall are dominated by natural gas and electricity consumption.

ARC – Unitary Plan Wind Tunnel





LaRC – Transonic Dynamics Tunnel



Facility Scope

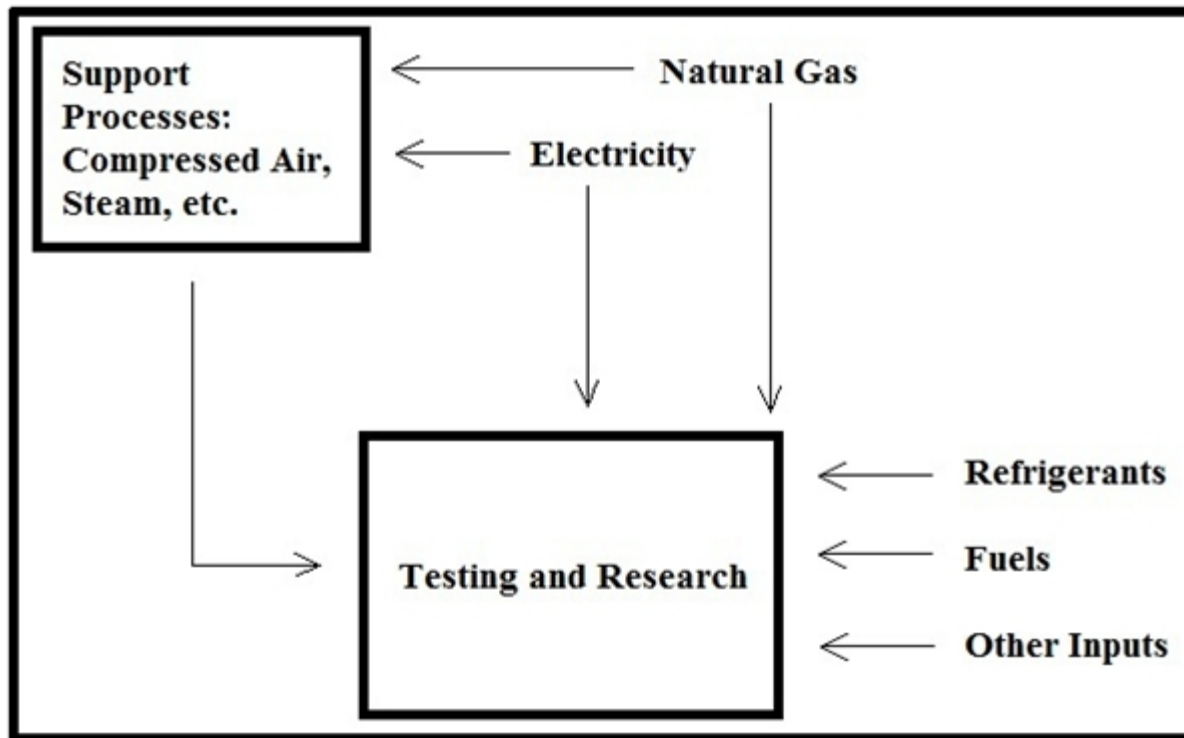
Construction

Spare Parts

Model Parts

Demolition

Glues/Cleaners



Trash/Recycling

Hydraulic Oils

Vehicle Fuels

Cooling Water

Life Cycle Inventory Data

- **Definition**

**All significant inputs and outputs
FY08-FY10 Average**

- **Process**

Inventory survey for facilities

**Data also collected through Center utility
management offices**

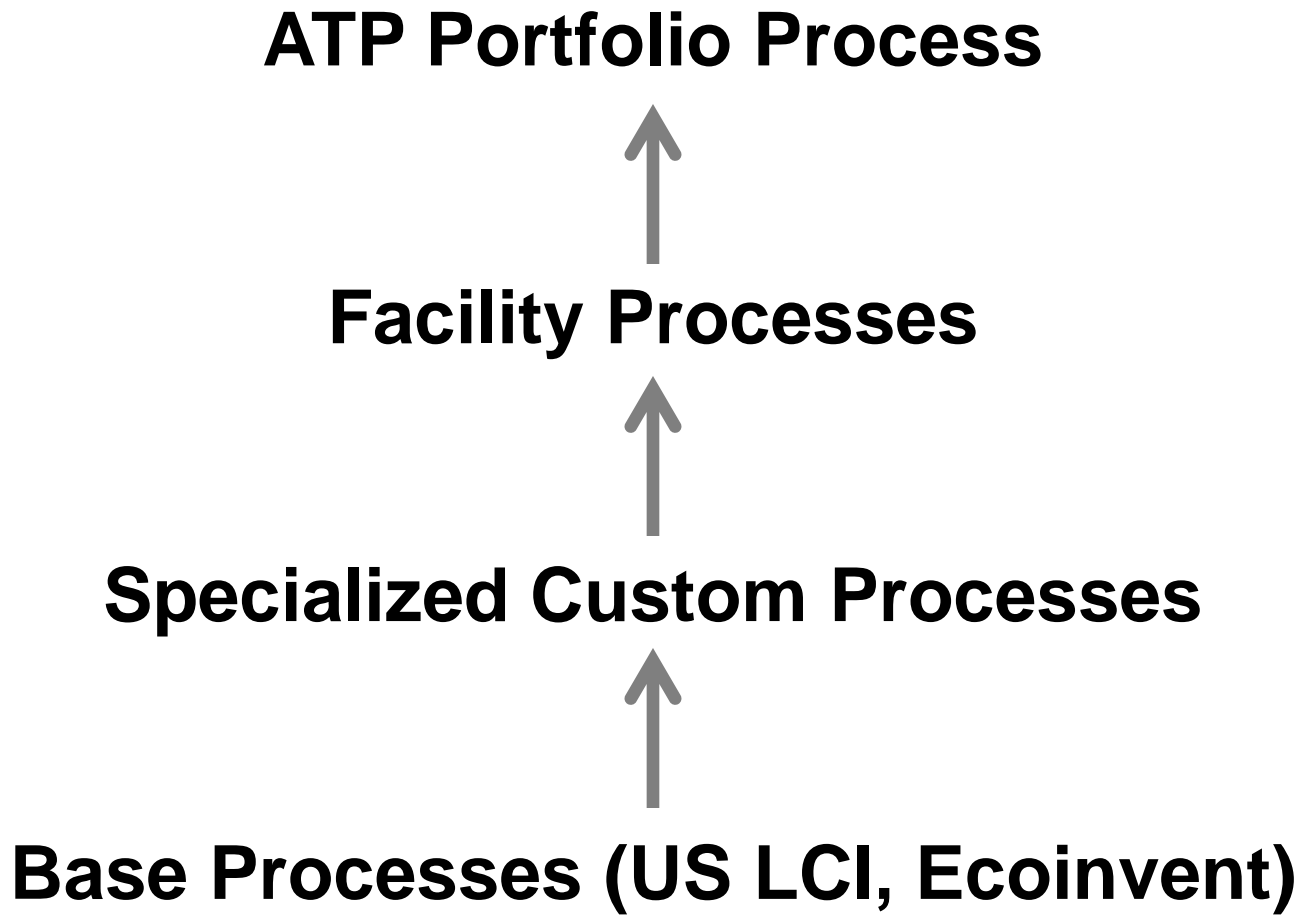
Baseline Model: SimaPro

Processes	Name	Unit
[-] Material	Cast iron, at plant/RER S	kg
[-] Agricultural	Cast iron, at plant/RER U	kg
[-] Animal production	Chromium steel 18/8, at plant/RER S	kg
[-] Animal food	Chromium steel 18/8, at plant/RER U	kg
[+] Food	Cold rolled sheet, steel, at plant/RNA	kg
[-] Others	Ferrite, at plant/GLO S	kg
[+] Plant oils	Ferrite, at plant/GLO U	kg
[+] Plant production	Galvanized steel sheet, at plant/RNA	kg
[+] Ceramics	Hot rolled sheet, steel, at plant/RNA	kg
[-] Chemicals	Iron and steel, production mix/US	kg
[+] Acids (inorganic)	Iron, sand casted/US	kg
[-] Acids (organic)	Pig iron, at plant/GLO S	kg
[-] Fertilisers (inorg)	Pig iron, at plant/GLO U	kg
[+] Fertilisers (orga)	Reinforcing steel, at plant/RER S	kg
[-] Gases	Reinforcing steel, at plant/RER U	kg
[-] Infrastructu	Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix	kg
[-] Inorganic	Steel hot rolled coil, blast furnace route, prod. mix, thickness 2-7 mm, width 600-2	kg
[+] Organic	Steel hot rolled section, blast furnace and electric arc furnace route, production mi	kg
[+] Others	Steel rebar, blast furnace and electric arc furnace route, production mix, at plant C	kg
[-] Pesticides	Steel, converter, chromium steel 18/8, at plant/RER S	kg
[+] Silicons	Steel, converter, chromium steel 18/8, at plant/RER U	kg
[+] Washing agents	Steel, converter, low-alloyed, at plant/RER S	kg
[+] Construction	Steel, converter, low-alloyed, at plant/RER U	kg
[+] Electronics		kg

Baseline Model: SimaPro

Known inputs from technosphere (materials/fuels)			
Name		Amount	Unit
Blast furnace/RER/I U		0.0000000000	p
Hard coal coke, at plant/RER U		9.724	MJ
Hard coal mix, at regional storage/UCTE U		0.15	kg
Iron ore, 65% Fe, at beneficiation/GLO U		0.15	kg
Limestone, at mine/CH U		0.01	kg
Natural gas, high pressure, at consumer/RER U		0.12	MJ
Pellets, iron, at plant/GLO U		0.4	kg
Refractory, fireday, packed, at plant/DE U		0.002	kg
Sinter, iron, at plant/GLO U		1.05	kg
Transport, barge/RER U		0.0165	tkm
Transport, freight, rail/RER U		0.25165	tkm
Transport, lorry >16t, fleet average/RER U		0.01004	tkm
Transport, transoceanic freight ship/OCE U		1.485	tkm
Known inputs from technosphere (electricity/heat)			
Name		Amount	Unit
Outputs			
Emissions to air			
Name	Sub-compartment	Amount	Unit
Carbon dioxide, fossil		0.84908	kg
Carbon monoxide, fossil		0.0013404	kg
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-		0.0000000000	kg
Heat, waste		14.284	MJ
Hydrogen sulfide		0.000010745	kg
Lead		0.0000000691	kg
Manganese		0.0000000744	kg

SimaPro Model Construction



Analysis

- **SimaPro software V7.3**

- **Methods:**

- **IMPACT 2002+**

Combination of popular methods (Eco Indicator, CML)

Separate climate change impact category

- **IPCC 2007 GWP 100a V1.02**

Similar to federal GHG inventory methods

Carbon Footprint

100-year GWP

Facility	Annual Carbon Footprint (tonnes CO₂e)
LaRC TDT	56,000
Ames UPWT	22,400
Glenn 9 x 15/8 x 6	21,700
LaRC NTF	19,100
LaRC Unitary	11,200
LaRC CF4	10,000
Glenn 10 x 10	8,580
Glenn IRT	8,460
Glenn PSL	7,530
LaRC 31/15- Inch	6,340
LaRC 8-Foot	3,000
LaRC 14 x 22	2,850
LaRC VST	349
Total	178,000

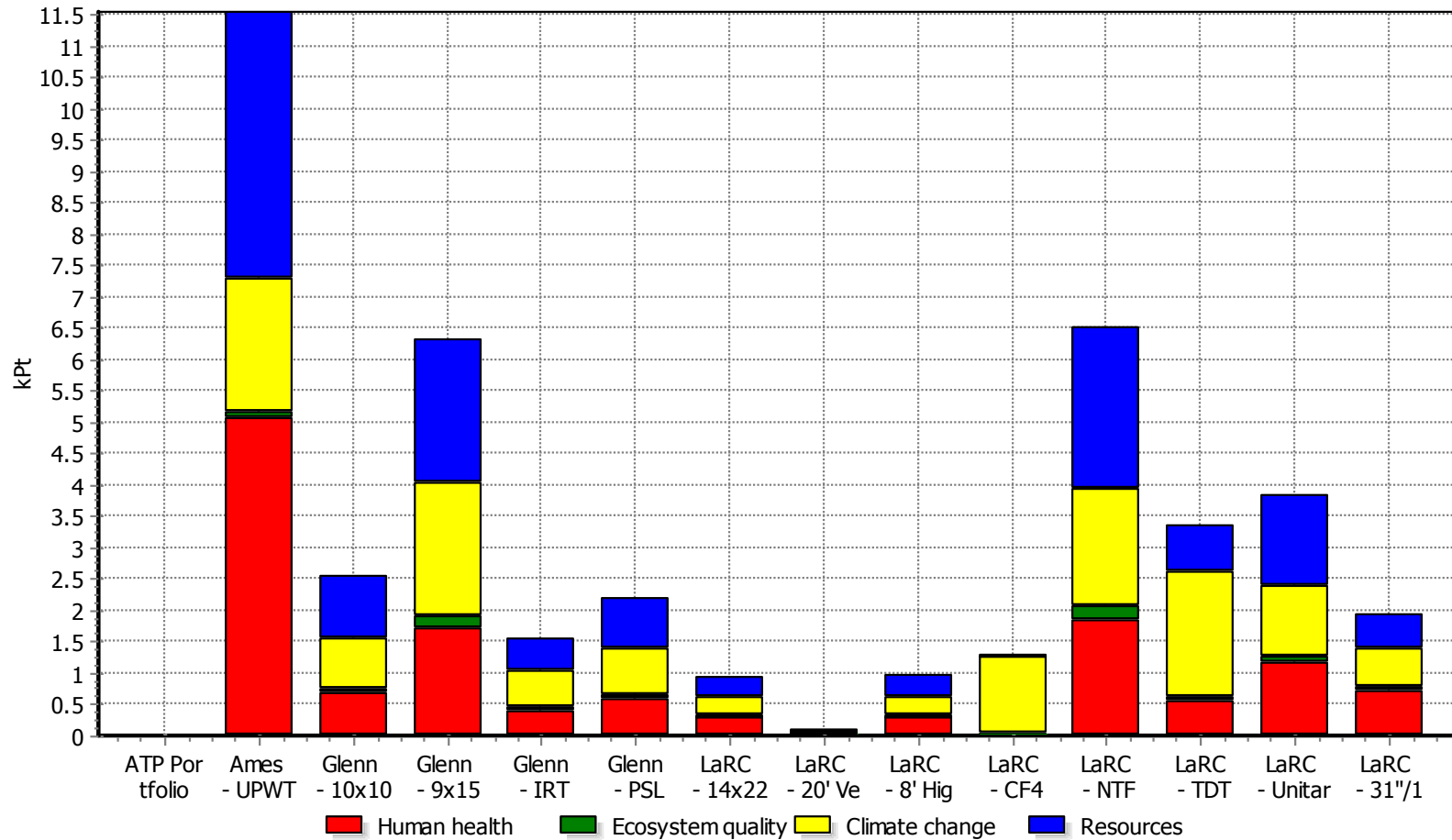
In comparison:

NASA: 1,300,000 MT CO₂e

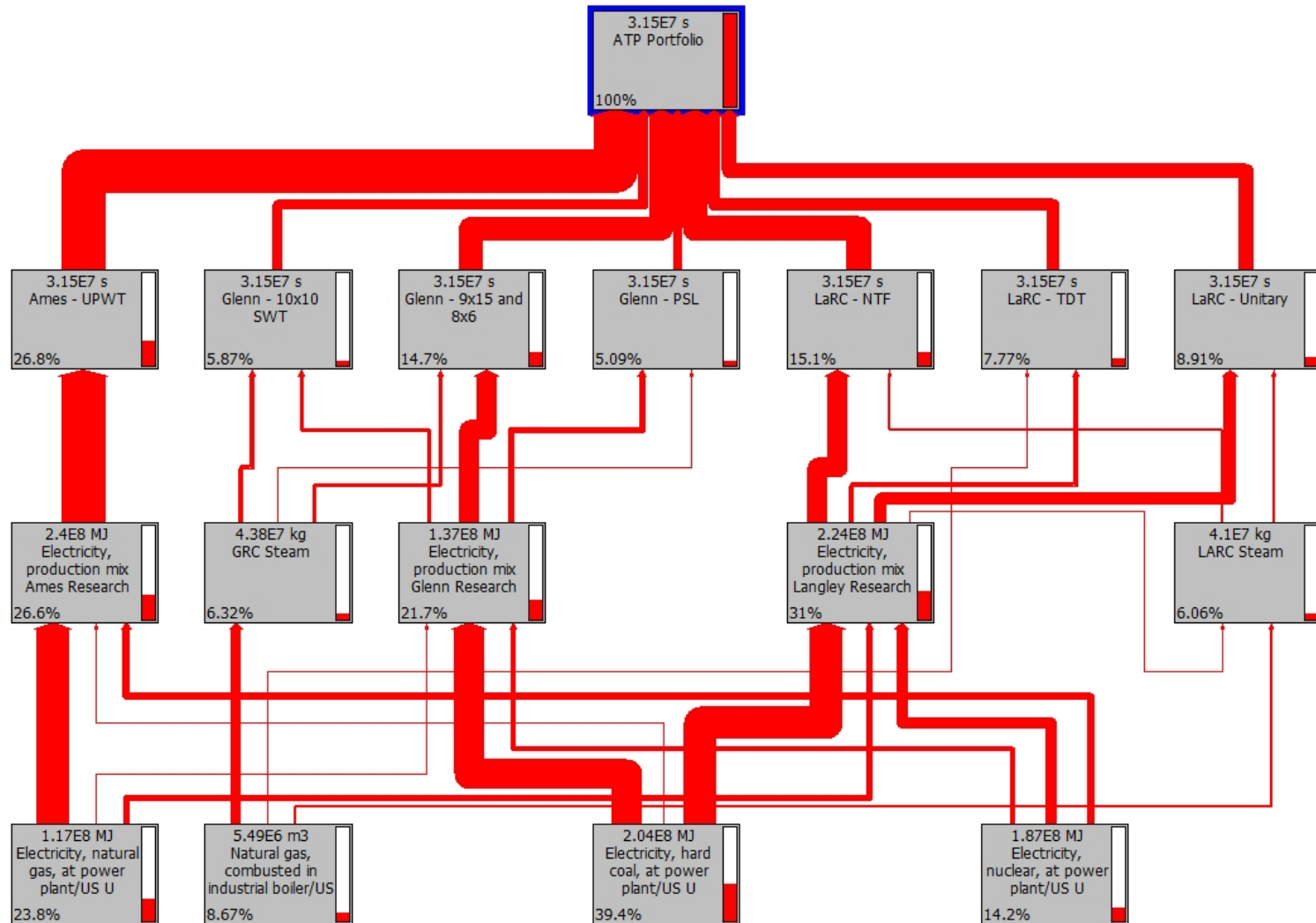
Avg. US Citizen: 18 MT CO₂e

**However, NASA calculations
are more general**

Environmental Impact



Environmental Impact



ATP Facility LCA Findings

- **Electricity and natural gas drive impacts**
 - Generally correlated to tunnel energy consumption
 - Exception: Specialized facilities
- **Four large facilities (of the 12 total) make up about 60% of carbon footprint and environmental impact**
 - 9 x 15/8 x 6 Wind Tunnel Complex, GRC
 - Ames Unitary Plan Wind Tunnel, ARC
 - National Transonic Facility, LaRC
 - Transonic Dynamics Tunnel, LaRC

Ames Arc Jet Complex

An aerial photograph of the Ames Arc Jet Complex, showing a large industrial facility with various components labeled. The complex includes several large spherical tanks, a central processing area with pipes and valves, and various support buildings. The labels indicate the names of the systems and the years they were installed or upgraded.

150 MW Power Supply
1975/2008/2014

Pollution Control
2011

DI Cooling
2007

Ejector-Condenser System
1961/2010/2017

Controls/Chambers/Exhausters
1975/2009/2015

High Pressure Systems
1961/2007/2018

Steam Boiler
1946/2010/2011/2013

SVS Cooling
2009

Ames Arc Jet Project Overview

Goal: Determine the life-cycle carbon footprint and selected environmental impacts of the NASA Ames Arc Jet Complex to provide insight on the Complex's largest impacts and evaluate reasonable alternatives to reduce those impacts.

Result: The Complex's impact is dominated by the natural gas-fired steam boiler; significant impact reductions involve modifying the boiler.

Arc Jet LCA: Data and Methods

- **Scope based on ATP study but more extensive**
- **LCI Data:**
 - 3 year average (CY09-CY11)
 - US LCI (85%) and Eco-invent (15%); more custom processes
- **LCA Analysis Method:**
 - Eco-Indicator 99 H/A
 - IPCC 2007 GWP 100a

Arc Jets Inventory: Results

INPUTS	Average Annual Consumption
Electricity	3,638.17 MWh
Natural Gas	80,040,000 SCF
Water	9,155,265 gal
Cooling Water Chemicals	395 gal
Caustic Solution	1,750 gal
DI Resin Bed Chemicals	495 gal
Argon	136,446 SCF
OUTPUTS	Average Annual Emission
Boiler Emissions	Included
Arc Jet NO _x Emissions	39.3 lb

Arc Jets: Carbon Footprint

Input/Output	Carbon Footprint, kgCO ₂ e	Percent
Boiler Emissions	4,440,000	81.187%
Natural Gas Consumption	1,000,000	18.285%
Water Usage	20,800	0.380%
Caustic Solution	6,220	0.114%
Argon Usage	828	0.015%
Cooling Water Chemicals	504	0.009%
DI Resin Bed Chemicals	242	0.004%
Electricity Consumption	229	0.004%
Arc Jet NO _x Emissions	0	0.000%
TOTAL	5,468,823	100.000%

Arc Jet Complex Annual Carbon Footprint: 5,468 MT CO₂e

In comparison:

NASA: 1,300,000 MT CO₂e

Avg. US Citizen: 18 MT CO₂e

Arc Jets: Env. Impacts

Input/Output	Env. Impact, Pts	Percent
Natural Gas Consumption	471,000	87.578%
Boiler Emissions	64,200	11.937%
Water Usage	1,860	0.346%
Caustic Solution	441	0.082%
Argon Usage	90	0.017%
Arc Jet NOx Emissions	79	0.015%
Cooling Water Chemicals	72	0.013%
Electricity Consumption	42	0.008%
DI Resin Bed Chemicals	21	0.004%
TOTAL	537,806	100.000%

Natural gas boiler dominates carbon footprint and environmental impact of complex.

Arc Jets: Alternatives Analysis

Five operational alternatives were identified for comparison to baseline model:

- 1. Replace boiler (in progress)**
- 2. Reduce boiler operation**
- 3. Install boiler cogeneration system**
- 4. Reduce electricity use**
- 5. Install JSC TP3 arc heater (in progress)**

Arc Jets: LCA Project Findings

- Overall, the natural gas-fired boiler dominates carbon footprint and environmental impact.
- Boiler replacement, as well as better operational management of boiler operation, could reduce impact by 15%.
- A cogeneration system presents modeling challenges but has the potential to reduce impact by up to 40%.
- Other inputs – water, chemicals, cryogenic fluids – do not significantly affect the Complex's impact.

NASA LCAs: Looking Forward

Data Gathering and Trending

- **Improvement of utility metering**
 - **Typically, largest impacts are utility related**
 - **Few utilities metered precisely**
Glenn Research Center – good example
- **Address inventory data management challenges**
 - **Most data is scattered; has scattered origins**
 - **Nature of research facilities leads to inconsistent, project-dependent data patterns**
 - **Center-to-Center differences hinder data collection**

NASA LCAs: Looking Forward

Modeling and Results

- **Standardization of data modeling and LCA analysis**
 - **Ames Research Center electricity**
- **Potential application of results: impact per MW, impact per test, etc. (Sensitivity/appreciation to results and possibilities)**
- **Incorporate specification criteria in new facilities, upgrades, and capabilities**